SSSC and TCPS Based Hydrothermal System to Improve Dynamic Performance Via FABFM

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Abstract

This paper investigates Automatic Generation Control (AGC) of hydrothermal system under deregulated environment. A novel dual mode controller is used in AGC and the optimization process is done by Fuzzy Adaptive Bacterial Foraging Method (FABFM). The dynamic performance of the system with regard to peak time, overshoot and settling time has been improved by means of Flexible AC Transmission Systems (FACTS) devices like Static Synchronous Series Compensator (SSSC) and Thyristor Controlled Phase Shifter (TCPS). There might be problems with present controllers to be solved by soft computing techniques. Some factors influencing the formulation of AGC problem are open transmission access and the evolving of more socialized companies for generation, transmission and distribution. Therefore, the effect of bilateral contracts on the dynamics should be considered in modern AGC systems. Results reveal that using dual mode controller based on FABFM plus SSSC and TCPS has much more dynamic efficiency than the system with integral controller.

Keywords

AGC; Dual Mode Controller; Fuzzy Adaptive Bacterial Foraging Method(FABFM); Static Synchronous Series Compensator(SSSC); Thyristor Controlled Phase Shifter(TCPS)

Introduction

The objective of a power system is to keep different kinds of balances such as between load-generation, scheduled and actual tie line flows. For the purpose of constant frequency as the primary index of healthy operation of system as well as the quality of supplied power to consumer, these two factors are employed. Considering load demand, generation is the parameter that maintains both of these. As frequency becomes low, generation is increased and if the actual outflow is greater than the scheduled, then it will be decreased. Since system conditions are always altering as a result of load variations during different hours of a day, it would be impractical to control these balances. The aim of AGC is to keep frequency almost constant and to regulate tie line flows (C. Concordia, 1954- M.L. Kothari, 1980- J. Nanda, 1983). The power system structure is changed, consequently, the growth of more specialized industries for generation (Genco), transmission (Transco) and distribution (Disco), under open market system (deregulation) has become conceivable. (R.P. Schulte, 1996) described the control of generation in deregulated power systems. To equilibrate reliability with economics Independent System Operator (ISO) as an unbiased coordinator has also been studied in (J. Kumar, 1997). The estimation of Automatic Generation control in a deregulated environment has been perused in [B. H. Bakken, 1998]. In addition, a detailed review of the subject and the simulation of an AGC system after deregulation is presented. Furthermore, making use of power electronic devices in power system control as FACTS results in flexible power system operation and control (P. Bhatt, 2010). In order to analyze the interconnected power system, SSSC and TCPS are considered beneficent for the tie-line power flow control of an interconnected power system.

Lately, different intelligent technique have been used widely in different fields of electrical engineering. A fuzzy controller in a three -area system in the presence of SMES units on each area has been presented in (A. Demiroren and E. Yesil, 2004). In (G. Panda, S. Panda and C. Ardil, 2009), by means of fuzzy controllers, a two-area thermal system has been simulated on the existence of limitations in the generation rate of units and the results obtained from this method have been compared with that by common proportional integral controllers. In (P. Bhatt, R. Roy and S.P. Ghoshal, 2009), a two-area system has been studied in the presence of TCPS and systems of capacitor energy storage where the designed PID-controller parameters have optimally been regulated using various methods of artificial intelligence. In (R.J. Abraham, D.Das and A. Patra, 2006) the effects of applying TCPS on controlling the real power exchange between areas of generation control system have been examined.

This paper presents the design of a dual mode controller for AGC of hydrothermal system via FABFM. The dynamic performance of the system with regard to peak time, overshoot and settling time has been improved by means of FACTS devices like SSSC and TCPS. Open transmission access and the evolving of more socialized companies for generation, transmission and distribution affect the formulation of AGC problem. Hence, the traditional AGC system is modified to consider the impact of bilateral contracts on the dynamics. Simulation results have demonstrated better dynamic performance via the proposed controller compared with integral controller and without SSSC and TCPS.

Problem Statement

Dynamic Model

In an AGC system, there is a connection between two areas under deregulated scenario. Area 1 consists of a reheat system and area 2 comprises hydro system. Here, in each area, three generators are supposed.

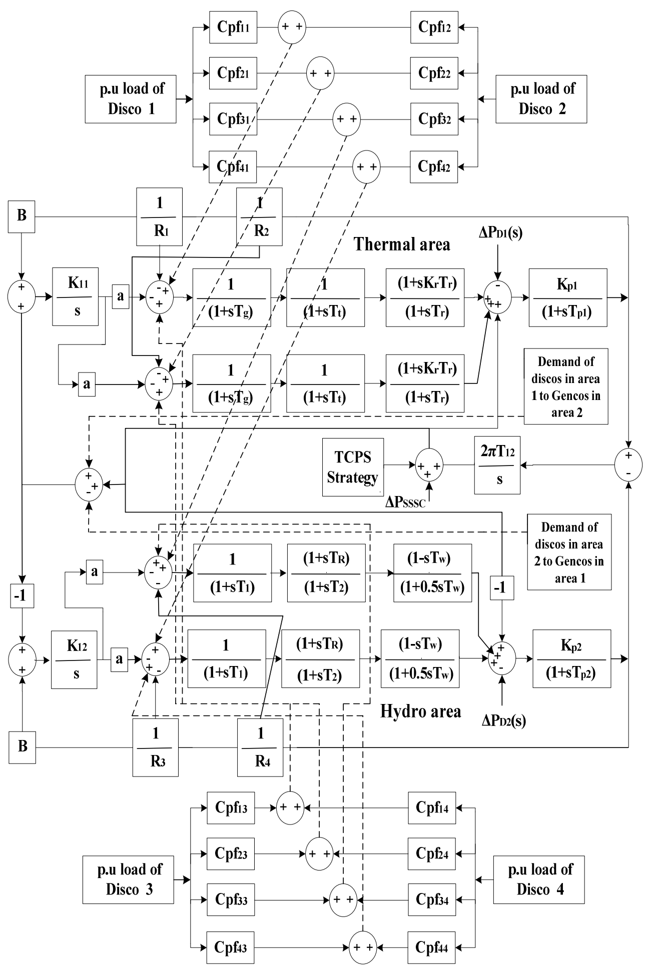

FIG. 1 TWO AREA HYDROTHERMAL SYSTEM

Fig. 1 depicts the block diagram of two-area hydrothermal system under open market scenario in which ACE of every area is fed to the corresponding controller. For every incoming ACE at the specific load variation, the precise control signal is produced. To compare the efficiency of both systems, a performance index is used as follows:

$$J = \int_0^t (\alpha.\Delta f_1^2 + \beta.\Delta f_2^2 + \Delta P_{tie\,12}^2) \quad (1)$$

Modeling of SSSC

In SSSC self-commutated voltage-source switching converters combines a three-phase voltage in quadrature with the line current. Such converters emulate an inductive or a capacitive reactance affecting the power flow in the transmission lines. The magnitude and polarity of injected voltage, *Vs* are the two factors for dynamically controlling compensation level. The device is in dual mode of capacitive and inductive. In order to stabilize the area frequency oscillations, the schematic of an SSSC in series with the tie-line between the interconnected areas by means of high speed controlling of the power is exerted, as shown in Fig. 2. The equivalent circuit of this system can also be represented by voltage source *Vs* in series with a transformer leakage reactance *Xs*. The voltage source *Vs* is the controllable factor of SSSC that actually represents the magnitude of injected voltage. Fig. 3 demonstrates the phasor diagram of the system considering the operating conditions of SSSC.

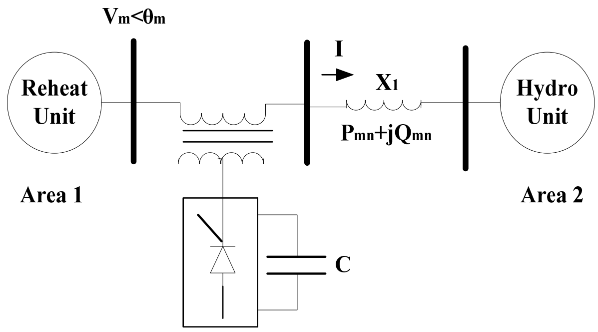

FIG. 2 SCHEMATIC OF SSSC APPLIED TO AGC

Based on the above figure when $Vs = 0$, the current Io of the system can be written as:

$$I_o = \frac{V_m - V_n}{jX_T} \quad (2)$$

Where $X_T = X_L + X_S$. The phase angle of the current can be expressed as:

$$\theta_c = \tan^{-1}\left[\frac{V_n \cos\theta_n - V_m \cos\theta_m}{V_m \sin\theta_m - V_n \sin\theta_n}\right] \quad (3)$$

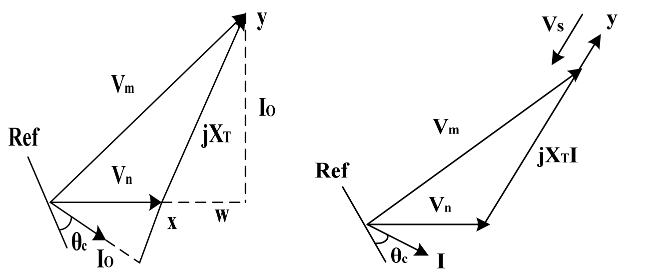

FIG. 3 PHASOR DIAGRAM AT VS=0 AND VS LAGGING I BY 90°

But Eqn (1) can be expressed in a generalized form as:

$$I = \frac{V_m - V_s - V_n}{jX_T} = \left[\frac{V_m - V_n}{jX_T}\right] + \left[\frac{-V_s}{jX_T}\right] = I_o + \Delta I \tag{4}$$

The term ΔI is an additional current term due to SSSC voltage V_s . The power flow from bus m to bus n can be written as $S_{mn}=V_m I^*=S_{mno}+\Delta S_{mn}$, which implies

$$P_{mn} + jQ_{mn} = (P_{mno} + \Delta P_{mn}) + j(Q_{mno} + \Delta Q_{mn}) \tag{5}$$

Where P_{mno} and Q_{mno} are the real and reactive power flow, respectively when V_s=0. The change in real power flow caused by SSSC voltage is given by:

$$\Delta P_{mn} = \frac{V_m V_s}{X_T}\sin(\theta_m - \alpha) \tag{6}$$

When V_s lags the current by 90°, ΔP_{mn} can be written as:

$$\Delta P_{mn} = \frac{V_m V_s}{X_T}\cos(\theta_m - \theta_c) \tag{7}$$

From Eqn (2) the term $\cos(\theta_m-\theta_c)$ can be written as:

$$\cos(\theta_m - \theta_c) = \frac{V_n}{V_m}\cos(\theta_n - \theta_c) \tag{8}$$

Referring to Fig. 3, it can be written as:

$$\cos(\theta_n - \theta_c) = \frac{yw}{xy} \tag{9}$$

And it can be seen as $yw=V_m \sin\theta_{mn}$

$$xy = \sqrt{V_m^2 + V_n^2 - 2V_m V_n \cos\theta_{mn}} \quad and \quad \theta_{mn} = \theta_m - \theta_n \tag{10}$$

Based on these relationships, Eqn (6) can be modified as follows:

$$\Delta P_{mn} = \frac{V_m V_n}{X_T}\sin(\theta_{mn}) \times \frac{V_s}{\sqrt{V_m^2 + V_n^2 - 2V_m V_n \cos\theta_{mn}}} \tag{11}$$

From Eqn (4), it can be written as $P_{mn} = P_{mno} + \Delta P_{mn}$ which implies

$$P_{mn} = \frac{V_m V_n}{X_T}\sin(\theta_{mn}) + \left(\frac{V_m V_n}{X_T}\sin(\theta_{mn}) \times \frac{V_s}{\sqrt{V_m^2 + V_n^2 - 2V_m V_n \cos\theta_{mn}}}\right) \tag{12}$$

Linearizing Eqn (12) about an operating point, it can be written as:

$$\begin{aligned}\Delta P_{mn} &= \frac{V_m V_n}{X_T}\cos(\theta_m - \theta_n)(\Delta\theta_m - \Delta\theta_n) \\ &+ \left(\frac{V_m V_n}{X_T}\sin(\theta_{mn}) \times \frac{V_s}{\sqrt{V_m^2 + V_n^2 - 2V_m V_n \cos\theta_{mn}}}\right)\end{aligned} \tag{13}$$

$\Delta P_{mn} = \Delta P_{tie} + \Delta P_{SSSC}$ which implies

$$\Delta P_{SSSC} = \frac{V_m V_n}{X_T}\sin(\theta_{mn}) \times \frac{\Delta V_s}{\sqrt{V_m^2 + V_n^2 - 2V_m V_n \cos\theta_{mn}}} \tag{14}$$

As stated in Eqn (14), it is clear that variations in the SSSC voltage ΔV_s, result in the controlling of SSSC's power which will consequently control the frequency and tie line deviations. The structure of SSSC to be included in the two area system in favor of reducing the frequency deviations is provided in Fig. 4. The frequency deviation of area 1 would act as input of the SSSC device.

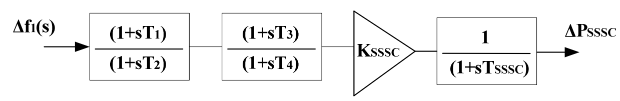

FIG. 4 SSSC STRUCTURE

Modeling of TCPS

Fig. 5 shows a two-area hydrothermal interconnected system assuming TCPS in series with the tie-line.

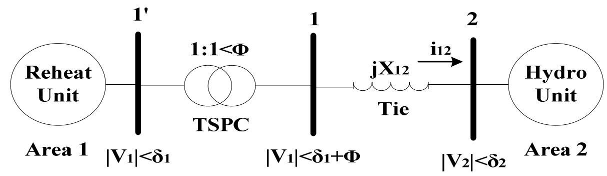

FIG. 5 SCHEMATIC OF TCPS IN SERIES WITH TIE LINE

Area 1 is the thermal one comprising three reheat units is followed by TCPS. Second area is the hydro one consisting of three hydro units. The incremental tie-line power flow from first area to second one with TCPS under open market system is expressed as Eqn (16).

The phase shifter angle $\Delta\phi(s)$ can be written as:

$$\Delta\phi(s) = \frac{K_\phi}{1 + sT_{ps}}\Delta Error_1(s) \tag{15}$$

Where K_ϕ and T_{ps} are the gain and time constants of the TCPS and $\Delta Error_1(s)$ is the control signal which controls the phase angle of the phase shifter. Therefore, it can be written as:

$$\begin{aligned}\Delta P_{tie12}(s) &= \frac{2\pi T_{12}'}{s}\left[\Delta F_1(S) - \Delta F_2(S)\right] + \\ T_{12}' &\times \frac{K_\phi}{1 + sT_{ps}}\Delta Error_1(s)\end{aligned} \tag{16}$$

$\Delta Error_1$ can be any signal such as the thermal area frequency deviation Δf_1 or hydro area frequency deviation Δf_2 .

Designing of Dual Mode Controller

The steady state zero error could be achieved by just implementing the well designed integral controller, but the response of the system becomes slow resulting from high overshoot and long settling time. The proportional controller by itself will improve overshoot and the speed of the response. Apparently, the presence of the proportional controller is compelling at transient states to make system response faster so as to reduce the overshoot. The main shortcoming of the proportional controller is that it fails to bring the steady state error to zero. So the usage of both the integral and proportional controller simultaneously seems urgent. In this study, effort has been made to develop a dual mode controller

Discontinuous Mode

The control law employed during the transient period, i.e., the discontinuous mode, is switched between Eqn (17) and Eqn (18) depending on the magnitude of error signal i.e., ACE(t). For $|ACE(t)|>\varepsilon$, the output of the controller is:

$$\Delta P_C(t) = -K_p . ACE(t) \tag{17}$$

Where $\Delta P_c(t)$ is output signal of the controller; ε is constant indicating the specified limit of error signal; K_P is proportional controller.

For $|ACE(t)|<\varepsilon$

$$\Delta P_C(t) = -K_i \int ACE(t)dt \tag{18}$$

Based upon the above mentioned facts, the dual concept is introduced here in the following way. The proportional controller will act during the transient period when the error (ACE) is sufficiently larger, whereas the integral controller would be the better option when the error is small.

The proposed control scheme is shown in Fig. 6 for which, the control law is taken as follows:

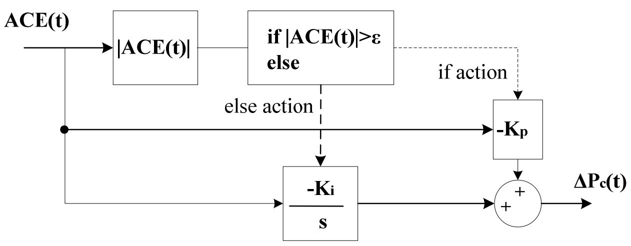

FIG. 6 BLOCK DIAGRAM OF THE PROPOSED CONTROLLER

$$\Delta P_{c1}(t) = -K_{p1}\left[ACE_1(t)\right] \qquad for\ |(ACE_1)| > \varepsilon_1 \tag{19}$$

$$\Delta P_{c1}(t) = -K_{i1}\left[\int ACE_1(t)\right] \qquad for\ |(ACE_1)| \le \varepsilon_1 \tag{20}$$

$$\Delta P_{c2}(t) = -K_{p2}\left[ACE_2(t)\right] \qquad for\ |(ACE_2)| > \varepsilon_2 \tag{21}$$

$$\Delta P_{c2}(t) = -K_{i2}\left[\int ACE_2(t)\right] \qquad for\ |(ACE_2)| \le \varepsilon_2 \tag{22}$$

Continuous Mode

In the continuous mode, the error signal remains within the specified limit, i.e., ACE(t). The integral control scheme is the most appropriate for the system entering the continuous mode. The frequency and tie line power error deviations of hydrothermal system under deregulated scenario could be controlled by parameters of the dual mode controller (k_P, k_i and ε). In both areas, the optimal value of k_P, k_i have been acquired by fuzzy adaptive bacterial foraging method.

Fuzzy Adaptive Bacterial Foraging Method

The survival of species in any natural evolutionary process depends upon their fitness criteria, which relies upon their food searching and motile behaviour. The law of evolution supports those species that have better food searching ability and either eliminates or reshapes those with poor search ability (K. M. Passino, 2002). The genes of those stronger species get propagated in the evolution chain since they possess ability to reproduce even better species in future generations. Therefore, a clear understanding and modeling of foraging behavior in any of the evolutionary species, leads to its suitable application in any non-linear system optimization algorithm. The foraging strategy of E.oli bacteria present in the human intestine can be explained by four processes namely Chemotaxis, Swarming, Reproduction, and Elimination & Dispersal**.**

Chemotaxis: The characteristics of movement of bacteria in search of food can be defined in two ways, i.e. swimming and tumbling together known as chemotaxis. A bacterium is said to be swimming if it moves in a predefined direction, and tumbling if moving in an altogether different direction. Mathematically, tumble of any bacteriumcan be represented by a unit length of random direction Φ(i) multiplied by a step length of that bacterium C(i). In case of swimming, this random length is predefined.

Swarming: For the bacteria to reach at the richest food location (i.e. for the algorithm to converge at the solution point), it is desired that the optimum bacterium till a point of time in the search period should try to attract other bacteria so that together

they converge at the solution point more rapidly. To achieve this, a penalty function based upon the relative distances of each bacterium from the fittest bacterium till that search duration, is added to the original cost function. Finally, when all the bacteria have merged into the solution point, this penalty function becomes zero. The effect of swarming is to make the bacteria congregate into groups and move as concentric patterns with high bacterial density.

Reproduction: The original set of bacteria, after getting evolved through several chemotactic stages reach the reproduction stage. Here, the best set of bacteria (chosen out of all the chemotactic stages) gets divided into two groups. The healthier half replaces the other half of bacteria, which gets eliminated, owing to their poorer foraging abilities. This makes the population of bacteria constant in the evolution process. The survival and elimination behavior of any bacterium is better known as its motile behavior.

Elimination and dispersal: In the evolution process, a sudden unforeseen event can occur, which may drastically alter the smooth process of evolution and cause the elimination of the set of bacteria and/or disperse them to a new environment. Most ironically, instead of disturbing the usual chemotactic growth of the set of bacteria, this unknown event may place a newer set of bacteria nearer to the food location. From a broad perspective, elimination and dispersal are parts of the population level long distance motile behavior. In its application to optimization, it helps in the reduction of the behavior of stagnation (i.e. being trapped in a premature solution point or local optima) often seen in such parallel search algorithms. The steps of the proposed FABF algorithm are described as follows:

Step 1. Initialization

a) Number of parameters (p) to be optimized.

b) Number of bacteria (S) to be used to search the total region.

c) Swimming length N_s after which tumbling of bacteria will be undertaken in a chemotactic loop.

d) N_c, number of iterations to be undertaken in a chemotactic loop ($N_c > N_s$).

e) N_{re}, the maximum number of reproduction to be undertaken.

f) N_{ed}, the maximum number of elimination and dispersal events to be imposed over bacteria.

g) P_{ed}, the probability with which the elimination and dispersal will continue.

h) The position of each bacterium $P(j,k,l) = \{\theta^i j,k,l) \mid i = 1,2,\ldots, S\}$ at the jth chemotactic step, kth reproduction step, and lth elimination-dispersal event.

i) The value of C(i) > 0, where i=1, 2, . . ., S denotes a basic chemotactic step size.

j) The values of $d_{attract}$, $w_{attract}$, $h_{repellant}$, and $w_{repellant}$ used for swarming.

There is a scope to fuzzify the variable C(i) arriving at the optimum value of the step size for the given problem in less time. Initially, the run length vector C(i) value is selected randomly and plays an important role in the convergence of SBF (Ch.Venkaiah, D.M. Vinod Kumar, 2011) algorithm. A small value of C(i) causes slow convergence, whereas a large value may fail to locate the minima by swimming through them without stopping. The selection of C(i) is tedious and time consuming in SBF. Hence, fuzzy adaptive scheme is utilized in C(i) to ensure the convergence of SBF algorithm. Here, the fuzzy input variables are taken as C(i) and the error from the objective function to obtain the fuzzy output as ΔC(i) for optimal value. The fuzzy logic rules are created by using fuzzy logic tool-box of MATLAB.

Step 2. Iterative algorithm for optimization: the algorithm that models bacterial population chemotaxis, swarming, reproduction, and elimination & dispersal is given here (initially, j = k = l = 0).

i. Elimination-dispersal loop: l=l+1.

ii. Reproduction loop: k=k+1.

iii. Chemotaxis loop: j= j+1.

a. For i = 1,2, . . ., S, a chemotactic step for bacterium i is taken as follows:

b. Compute $J_{error}(i,j,k,l)$ Let

$$J_{error}(i,j,k,l) = J_{error}(i,j,k,l) + J_{cc}(\theta^i(j,k,l), P(j,k,l))$$

Let $J_{last} = J_{error}(i,j,k,l)$ to save this value since a better cost can be drived via a run.

c. Tumble: generate a random vector $\Delta(i) \in R^p$ with each element $\Delta_m(i)$, m= 1, 2, ..., p, a random number on [−1, 1].

d. Move: let

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + c(i)\Delta(i)\Big)\overline{\Delta^T(i)\Delta(i)}$$

This results in a step of size C(i) in the direction of the tumble for bacterium i

e. Compute $J_{error}(i,j+1,k,l)$, and then let

$$J_{error}(i, j+1, k, l) = J_{error}(i, j+1, k, l) + J_{cc}(\theta^i(j+1, k, l), P(j+1, k, l))$$

f. Swim: Let m= 0 (counter for swim length) while m< N_s (if it hasn't climbed down too long)

g. Let m=m+1

h. If $J_{error}(i, j+1, k, l) < J_{last}$ (if doing better), let $J_{last} = J_{error}(i, j+1, k, l)$ and let $\theta^i(j+1, k, l) = \theta^i(j, k, l) + c(i)\Delta(i) \Big/ \sqrt{\Delta^T(i)\Delta(i)}$ and use this $\theta^i(j+1, k, l)$ to compute the new $J_{error}(i, j+1, k, l)$ as we did in f. Else, let m = N_s. This is the end of while statement j. Go to next bacterium (i +1) if i ≠ S (i.e. go to b) to process the next bacterium.

i) If j < Nc, go to chemotaxis loop (3) of Step 2. In this case, chemotaxis continues, since the life of the bacteria is not over.

ii) Reproduction: $J^i_{health} = \sum_{j=1}^{Nc+1} J_{error}(i, j, k, l)$

a. For the given k and l, and for each i = 1, 2, ..., S, $J^i_{health} = \sum_{j=1}^{Nc+1} J_{error}(i, j, k, l)$ be the health of bacterium i (a measure of how many nutrients it got over its life time and how successful it was at avoiding noxious substances). Sort bacteria and chemotactic parameters C(i) in order of ascending cost J_{health} (higher cost means lower health)

b. The S_r bacteria with the highest J_{health} values die and the other S_r bacteria with the best values split (and the copies made are placed at the same location as their parent).

iii) Chemotaxis loop: j=j+1. If k<N_{re}, go to reproduction loop (2) of step 2. In this case, we have not reached the number of specified reproduction steps, so we start the next generation in the chemotactic loop.

iv) Elimination-dispersal: for i=1, 2, ..., S, with probability p_{ed}, each bacterium is eliminated and dispersed (this keeps the number of bacteria in the population constant). To do this, if you eliminate a bacterium, simply disperse one to a random location on the optimization domain.

v) If l<Ned, then go to elimination-dispersal loop (1) of step 2; otherwise end.

The flow chart of the proposed FABF algorithm is shown in Fig. 7.

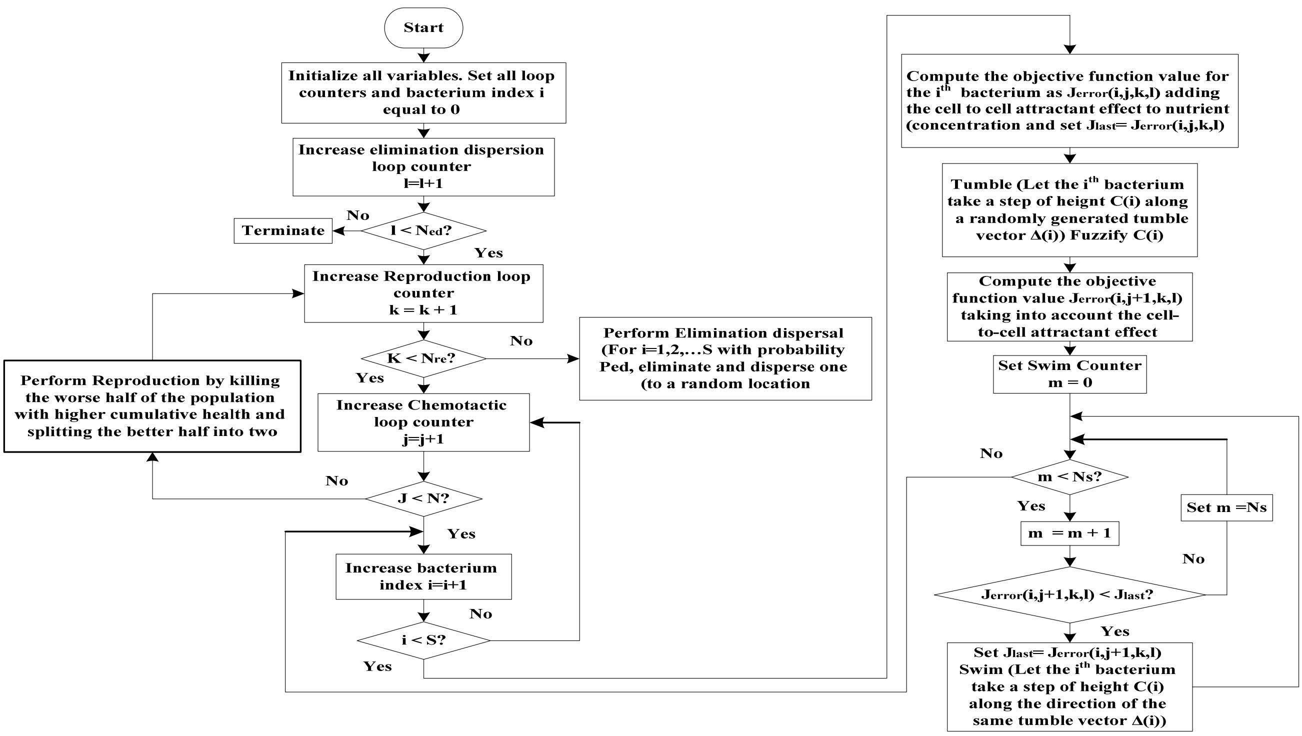

FIG. 7 FLOW CHART OF THE PROPOSED FABFM

TABLE 1 COMPARATIVE ANALYSIS

Mode	Thermal area			Hydro Area		
	Peak Time	*Overshoot*	*Settling Time*	*Peak Time*	*Overshoot*	*Settling Time*
Without SSSC-TCPS-Integral Controller	3.231	0.7563213	6.461	4.658	0.9465681	5.434
With SSSC-TCPS-Dual Mode	2.216	0.0963215	1.886	2.365	0.0975945	2.864
% Improvement	31.41	87.26	70.809	49.227	89.68	47.29

Simulation Result

A load change of 0.04 p.u M.W in each area has been considered to study the comparison between both the system with SSSC, TCPS and FABFM based Dual Mode controller and the system with conventional integral controller and without SSSC, TCPS. A value of 0.5 has been considered as the gain of integral controller. Due to application of FABFM to the system, the optimum values of integral controller and proportional controllers in both areas i.e., $K_{i1}=K_{i2}=7373.26$ and $K_{p1}=K_{p2}=8826.125$ are obtained. A value of $\varepsilon_1=\varepsilon_2=0.02$ has been considered in this work as the specified limit of error signal in the design of dual mode controller. Table 1 shows the comparison of both the systems. The Discos contract with the Gencos as per the following Disco participation matrix:

$$DPM = \begin{bmatrix} 0.1 & 0.0 & 0.3 & 0.4 \\ 0.0 & 0.1 & 0.0 & 0.2 \\ 0.3 & 0.4 & 0.1 & 0.0 \\ 0.2 & 0.0 & 0.2 & 0.1 \\ 0.2 & 0.3 & 0.0 & 0.1 \\ 0.2 & 0.2 & 0.4 & 0.2 \end{bmatrix}$$

Table 2 shows the comparison of performance index of the system with SSSC-TCPS-Dual Mode and without SSSC-TCPS-Integral controller where the first one has less performance index than the last one.

TABLE 2 COMPARISON OF PERFORMANCE INDEX

	Performance Index Value
With SSSC-TCPS-Dual Mode	1.086×10e-5
Without SSSC-TCPS-Integral Controller	4.7026×10e-5

The various frequency deviations and tie line power deviations in both areas during a load change of 0.04p.u MW are shown in Fig. 8. The generations of various Gencos in area 1 and 2 are depicted in Fig. 9 and Fig. 10, respectively. As observed, the system with SSSC-TCPS-Dual Mode is far superior to the system without SSSC-TCPS-Integral controller in terms of peak time, overshoot and settling time in both the areas. Three generators in each area have been considered for the study. Each Genco participates in AGC is defined by following area participation factors (apfs): apf1=0.5, apf2=0.25, apf3 =0.25, apf4 =0.5, apf5 =0.25, apf6 =0.25. Coefficients that distribute ACE to several Gencos are termed as "ACE participation factors" (apfs). It should be noted that m in $\sum_{j=1}^{m} apf_j = 1$ is the number of Gencos.

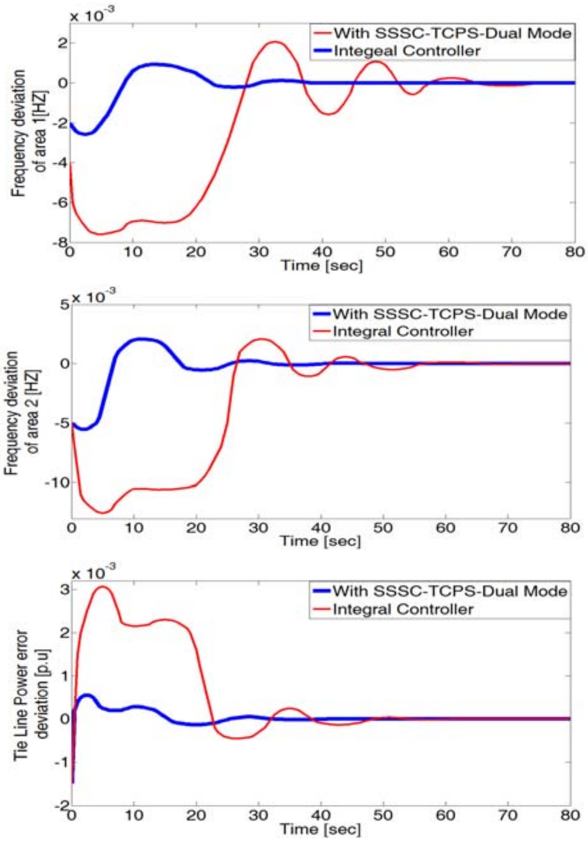

FIG. 8 FREQUENCY AND TIE-LINE POWER DEVIATIONS DURING A LOAD CHANGE

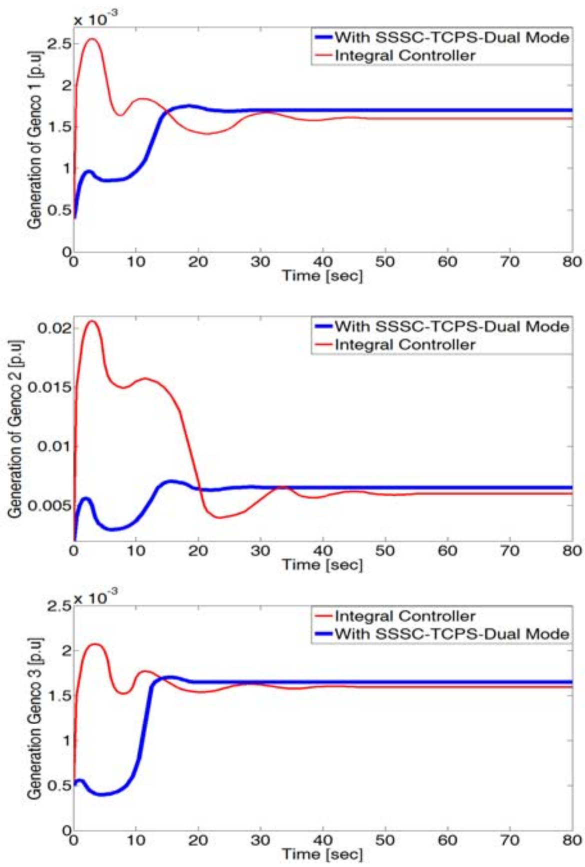

FIG. 9 GENERATION OF GENCOS IN AREA 1

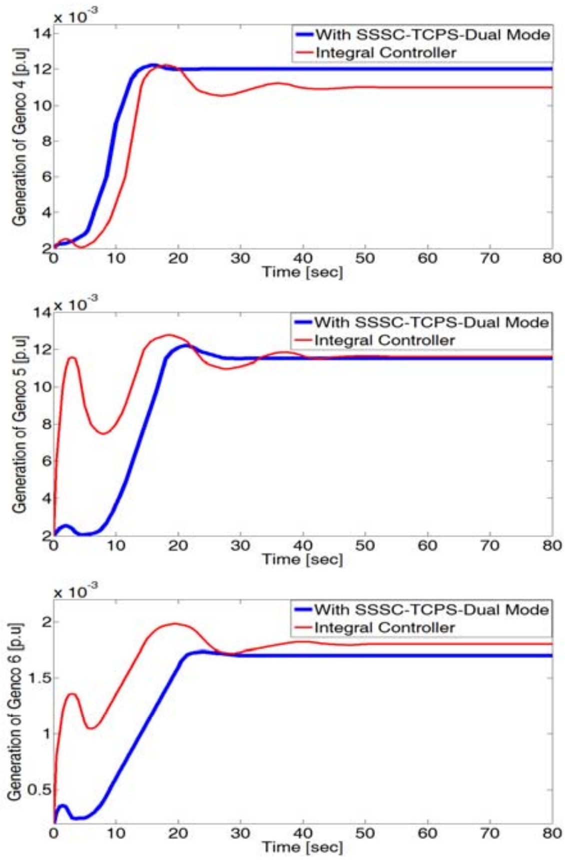

FIG. 10 GENERATION OF GENCOS IN AREA 2

The comparison between the performance index of both the systems is demonstrated in Fig. 11. As seen, the system with SSSC-TCPS-Dual Mode has less performance index than that without SSSC-TCPS-Integral Controller.

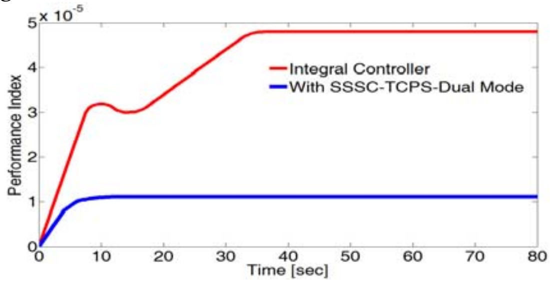

FIG. 11 COMPARISON OF PERFORMANCE INDEX

Conclusions

In this paper, a methodical FABF technique is employed to design dual mode controller for AGC of hydrothermal system under a deregulated environment. SSSC and TCPS are also used to improve the dynamic performance of the system concerning the reduction of frequency deviations and tie line power deviations during a load change on a two area hydrothermal system. This paper focused on the development of a new control strategy for SSSC-TCPS-dual mode controller is proposed and as well, the proposed control algorithm can bring several advantages such as follows:

- The ability to jump out the local optima, the convergence precision and speed are remarkably enhanced and thus the high precision and efficiency are achieved.
- A control strategy has been proposed to control the TCPS phase angle by adjusting the voltage of SSSC which in turn controls the inter-area tie-line power flow.
- The first peak frequency deviation of both areas and tie-line power oscillations following sudden load disturbances in either of the areas can be suppressed by controlling the phases angle of TCPS or the series voltage of SSSC.
- The superiority of the proposed SSSC-TCPS-dual mode controller is demonstrated owing to the less performance index in comparison with the system without SSSC-TCPS-Integral controller.

The simulation results reveal that the proposed technique successfully mitigates the frequency and tie-line power deviations during a load change. Furthermore, the tie-line power flow controlled by an SSSC units is found to be more efficient and effective to improve the dynamic performance of load frequency control over inter connected power system than that of the system with TCPS or without FACTS controllers. The tie line power flow controlled by an SSSC can be expected to be utilized as new ancillary service for stabilization of frequencies and tie-line power oscillations in the congestion management environment of the power system.

Appendix 1:

Δ_{Fi} : The deviation of ith frequency(i=1, 2).

Δ_{P12} : The deviation of the power exchanged between the first and second area.

Δ_{PMi} : The mechanical output power deviation of turbine of ith area.

Δ_{PL} : Changing in the electrical load.

P_{Ri} : The nominal capacity of generation of ith area.

KR_i : The integral coefficient of system of ith area.

ACE_i : The control line of ith area.

B_i : The bias coefficient of frequency of ith area.

T_{Gi} : The governor time constant of i[th] area.

R_i : The integrating feature of speed (Drop) of area i[th] area.

T_{Pi} : The time constant of the power system of i[th] area.

K_{Pi} : The power coefficient of the i[th] unit.

T_T : The time constant related to steam inertia in input piping and the steam treasury of thermal turbine.

T_{RH} : The time constant related to steam inertia in the process of re-heating of thermal unit turbine.

F_{HP} : The coefficient related to power generated in the high pressure steam part of thermal turbine.

F_{LP} : The coefficient related to the power generated in the medium pressure steam part of thermal turbine.

T_W :The time constant of initiating water in hydro turbines.

R_F : The integrating speed feature of continual state of mechanical governor in each unit.

R_T : The integrating speed feature of transient state of mechanical governor in each unit.

T_R : The reset time constant of mechanical governor in each unit.

$K\varphi$: The coefficient of phase shifter system.

T_F : The time constant of phase shifter system.

J : System objective function.

Appendix 2:

- Data for Thermal Reheat Power System (I.A. Chidambaram and S. Velusami, 2005) Rating of each area = 2000 MW, Base power = 2000 MVA, fo = 60 Hz, R1 = R2 = R3 = R4 = 2.4 Hz / p.u.MW, Tg1= Tg2 = Tg3 = Tg4 = 0.08 sec, Tr1 = Tr2 = Tr1 = Tr2 = 10 sec, Tt1 = Tt2 = Tt3 = Tt4 = 0.3 sec, Kp1 = Kp2 = 120Hz/p.u. MW, Tp1 = Tp2 = 20 sec, $\beta_1 = \beta_2 =$ 0.425 p.u. MW/Hz, Kr1 = Kr2 =Kr3 = Kr4 = 0.5, $2\pi T12$ = 0.545 p.u.MW / Hz, a12 = -1, Δ_{PD1}=0.01 p.u.MW
- Data for TCPS (R. J. Abraham, D. Das and A. Patra, 2006): $K\phi$ =1.5 rad/Hz, $\phi_{\max} = 10^o$, $\phi_{\min} = -10^o$, Tps = 0.1 sec.
- Data for SSSC (I. Ngamroo, 2001): Tsssc=0.03 sec, Tw=10 sec

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